Control and Monitoring of EME Solid-state Amplifiers

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When running a small dish on EME, every tenth of a dB of loss counts. This applies to loss in front of the preamp but also to loss in the transmit feeder. Running a large amplifier in the shack and sending the power to the dish through the largest diameter coaxial cable is one solution but it is costly. The power loss could be minimised by mounting the amplifier at the dish but this is impractical with a tube amplifier and its associated high voltage power supplies. In the past few years an increasing number of solid state amplifier designs have become available. Examples are the W6PQL 400 W amplifier for 1296 MHz [1], the Toshiba 50 W amplifier for 3.4 GHz [2] and the I0JXX 500 W amplifier for 144 MHz [3]. These can be safely mounted at the dish as they run from a relatively low voltage.

The issues with remote mounting of these amplifiers are:

- How to monitor the amplifier's status and performance from the operating position
- How the amplifier can protect itself.

In this paper I will discuss how I achieved this with three different amplifiers.

Monitoring and Display

It was decided that four parameters needed to be monitored. In all cases it is very necessary to provide adequate RF decoupling of the lines to be monitored, to prevent the measurements from being corrupted.

- **Voltage:** It is necessary to measure the supply voltage applied to the RF modules. If is voltage is either too high or too low, the amplifier must be switched offline.
- **Current:** It is necessary to monitor the supply current to the amplifier (separately to various stages, if necessary) to ensure that the standing bias currents and the driven currents are normal. Again the amplifier must be switched offline if any currents are excessive, such as when there is a faulty device or if the amplifier is being overdriven.
- **Temperature:** It is necessary to measure temperature to allow the amplifier fans to be controlled appropriately, and this can also be used to keep the amplifier offline if it gets really hot
- **Forward and reflected power:** It is nice to be able to see that the amplifier is putting out the normal power, but it is more important to switch the amplifier offline quickly if excessive reverse power is detected.

As well as monitoring these parameters and taking the necessary actions, the measurements and status information need to be displayed. The cheapest solution is to use an LCD display. Normally the display shows real time parameters, but when an alarm is triggered it shows the alarm type and the value that triggered the alarm to help in fault diagnosis

Control Circuitry

Fan control

The amplifier fan(s) can remain off until the amplifier is first used, but then need turning on when the temperature reaches the chosen lower trigger point. The fans also need turning off when the amplifier cools down, but the switch-off temperature should be some way below the switch-on temperature to avoid rapid cycling of the fans, which will be annoying.

Preamp sequencing

Along with all these other activities, the associated preamplifier and antenna relay need switching appropriately in response to either the PTT signal or any system-generated alarms. Control signals should be sequenced with suitable delays between events to enable relays to settle. It is also necessary to terminate the preamp in 50 Ω when on transmit, and also to allow routine measurements of the (cold sky : 50 Ω) Y-factor as an overall integrity check.

Control software

The software was developed for a PIC controller using the free MPLAB Integrated Development Environment. It was written in assembler language, as I like the challenge! The assembler listing runs to 6 pages (with comments) and is provided on the Conference DVD, along with many other details of this project.

At a high level, the control software does the following:

1. Initialize parameters
2. Initialize display and show welcome messages
3. Measure all A to D converter inputs
4. Convert voltage reading to volts, check for alarms and act accordingly
5. Convert current reading to amps, check for alarms and act accordingly
6. Convert temperature reading to °F, check for alarms, control fan
7. Convert forward power reading to watts, check for alarms and act accordingly
8. Convert reverse power reading to watts, check for alarms and act accordingly
9. Display results on LCD
10. GOTO 3

Having seen what is needed to control and monitor an amplifier, it is now time to put it all together. In the rest of this paper, I will show how the basic concept has been utilized for three well known types of SSPA.

1296 MHz 400 W W6PQL Amplifier

The W6PQL 1296 MHz amplifier consists of two RF modules each containing two XRF286 transistors, with hybrid combiners at input and output [1].It runs from 28 V and each module takes 16.5 A for a total of 33 A. For 20 W of drive it produces 400 W output.

Initially a controller was designed to fit inside the amplifier and drive a front panel status display. Figure 1 shows the modules mounted on the heatsink and connected to the PIC controller and local display. This was then developed into a design capable of communicating from a remote installation.

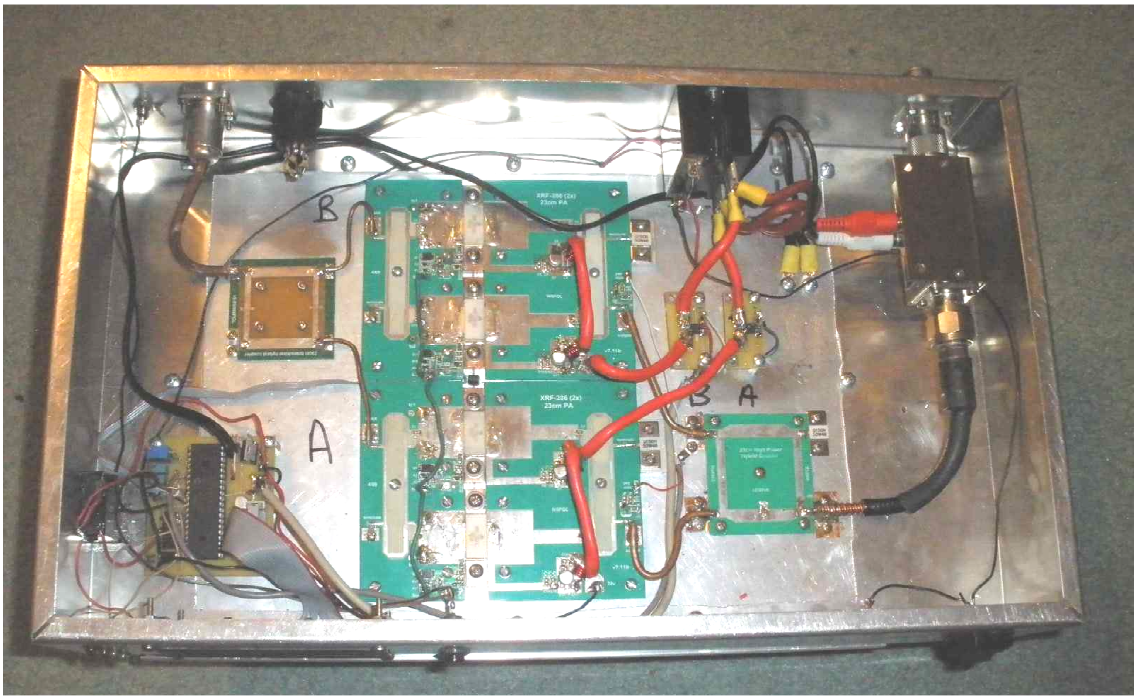


Figure 1: RF modules of W6PQL amplifier connected to the PIC controller and local display (lower left)

Hardware

The four parameters that needed to be monitored have already been identified:

- **Voltage:** The supply voltage is fed through a fixed resistor and a potentiometer to an A to D input pin of the PIC controller. As voltages much above 5 V could kill the PIC, a 5.1 V Zener diode is connected across the input pins.
- **Current:** Initially an op-amp was used to measure the voltage drop across a small resistor in the supply feed. This was only partially successful due to the voltage drop that was for reliable results. I then came across the Lossless current monitor design by Paul Wade W1GHZ. This used a commercial Hall effect device and measured 50 A using an Allegro ACS754 device [4]. This looks like a 3 legged TO220 power transistor with two large “lobster claw” appendages. Current passes between the two big leads, so there is very little voltage drop but it generates a magnetic field, which is measured and amplified to a calibrated output voltage. There are lower current 20 and 30 A versions in an 8 pin SOIC device. For ease of monitoring, I used a separate 20 A SOIC device ACS713-20 [5] in each PA module to measure the current of the two semiconductors together. These devices produce 2.5 V output for zero current and 5 V when 20 A is drawn.
- **Temperature:** I used the National LM35Z [6] which is a 3-terminal TO92 package device that runs from a 5 V supply and produces 10 mV per degree Fahrenheit. This is measured using an A to D converter in the PIC, and the value processed numerically by the controller. The sensor was mounted in the centre of the heatsink between the two PA modules.
- **Forward and reflected power:** I was lucky to obtain a dual directional coupler with integrated detectors, which was designed for use in cellular applications and is rated up to 1 kW. Externally accessible pots can calibrate the forward

and reflected voltage outputs. Forward power of 500 W at 1296MHz was set to produce 5 V. Reverse power was set to produce 5 V at 50 W. As a precaution, the ADC inputs are once again protected by 5.1 V Zener diodes.

Display

I chose a 16x4 character backlit display for ease of viewing. I initially tried a colour LCD display (as used on some cellphones) which looked very pretty but was hard to read at a distance. To reduce the pin count needed on the controller, the LCD is operated in 4-bit mode (where the 8 bits of data are sent as two groups of 4 bits which takes more time). The display uses the Hitachi HD48770 chipset, which is well documented and used in many applications.

Controller

Having had experience of Microchip PICs over the last 15 years, I decided to use one of these as a controller. My previous designs had used a 28-pin chip but this project needed a 40-pin chip to provide all the necessary I/O pins and ADC inputs: the two current sensors, voltage monitor input, temperature input, power measurement inputs, LCD output, three LED outputs and three switch inputs for local control. As serial data will be used for communication an onboard UART is also needed. The chosen device was the 16F887 which has 40 pins, a UART, eleven 10-bit A to D converters, an internal clock oscillator (which saves two external pins) and is Flash programmable making software updates easy.

Circuit

The PIC is capable of supplying or sinking tens of milliamps of current so a higher current interface to the outside world is needed. I used IRFD020 N-channel MOSFETs in a 4 pin DIL package. These devices are capable of continually carrying 2 A with an on-resistance of a hundred milliohms. They are used to switch the antenna relay in the preamp, the preamp input protection relay, bias relay and fan.

Three LEDs provide at-a-glance monitoring of the PA status: Transmit, Preamp Terminated and Alarm. The three switch inputs for local control are: PTT, Alarm Reset and a manual facility to terminate the LNA in 50 Ω for receiver testing. If the Alarm LED comes on, the type of error is also displayed on the LCD awaiting user intervention.

Figure 2 (next page) is the circuit diagram of the PIC controller for the W6QPL 400W SSPA. Even without studying the details, the circuit is clearly quite simple and easy to construct on a small circuit board. For more detailed study, full-sized bitmap images and the native .sch files from *ExpressSCH* [7] are available in my folder on the Conference DVD.

Software

The continuously looping algorithm for monitoring and control has already been outlined. In this particular application with two amplifier modules, the voltage and current measurements have to be repeated for each amplifier.

For the Hall effect current sensors, the PIC contains a lookup table to convert the reading from the A to D conversion (0..255) to the true current in amps. The forward and reverse RF power detectors have a square law characteristic, so the voltage outputs were converted to power readings using 16-bit arithmetic functions in the PIC.

In the software, the voltage trip is set at 28.6 V, the current trip is set at 19 A for either module and the temperature that trips the amplifier into permanent bypass mode is 110°F. The fan runs continually when the amplifier is transmitting. On receive the fan

runs if the chassis temperature exceeds 92°F and stops when the amplifier chassis cools to 90°F. These values worked fine in hot Texas but will probably need adjustment for cooler climates!

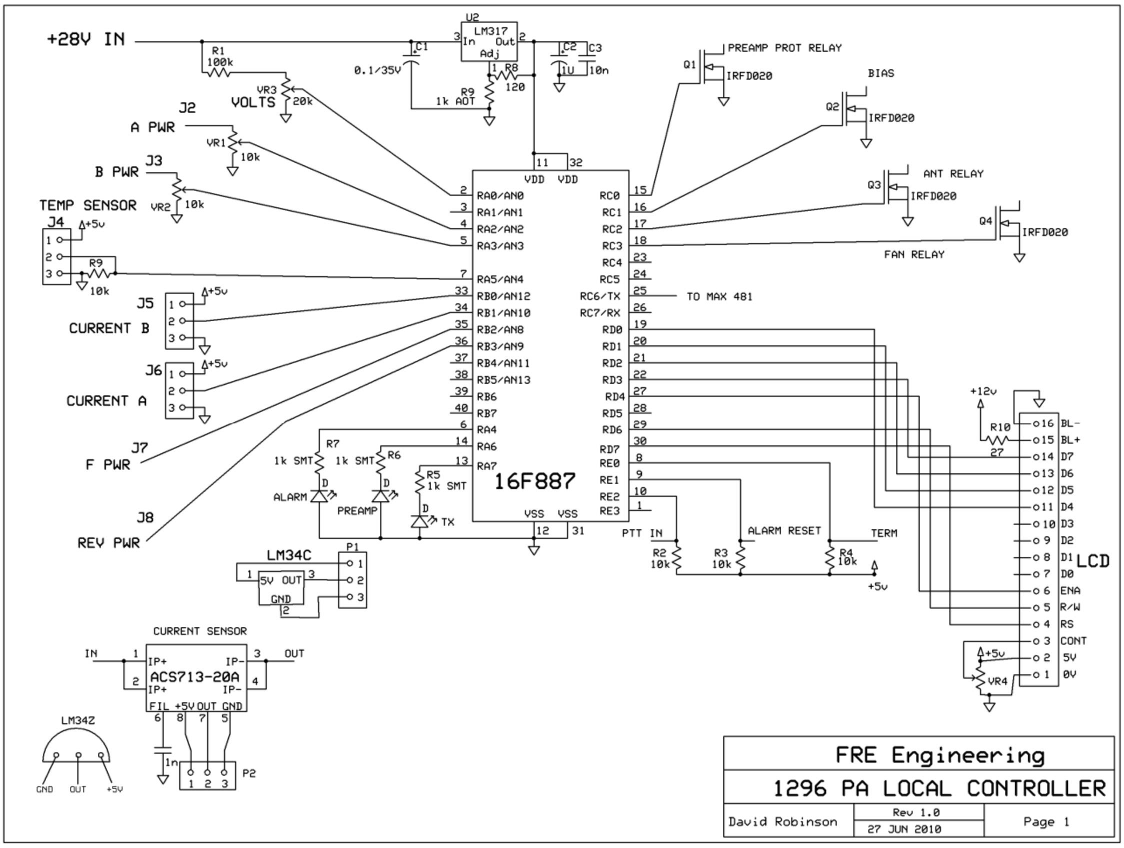


Figure 2: Circuit of W6PQL amplifier Local controller

Remote Monitoring

Having got the amplifier running with a local control and display, the next task was to see how to monitor and control the amplifier at a distance. To monitor remotely, a box with a duplicate LCD display and switches would be needed. The first issue to investigate was how to communicate remotely to the amplifier.

I standardized on screened keyboard extension cables with 6-pin mini-DIN plugs on each end, which are available in 50, 75 and 100 ft lengths. The distance from EME shack in the garage and the dish was 60 ft. Initially I used the RS232 Interface as I had the driver chips (MAX232) but soon learned that this was an excessive distance for reliable operation. I then investigated how others were communicating with remote sensors to control the dish position from the shack computer. They seemed to use the balanced version of RS422 with success. I changed the MAX232 driver chip to a MAX481 and reliable communication with the remote amplifier was successful using the same cable. The pin designations are as follows:

1. Ground
2. Alarm reset
3. 12V (from amplifier to power display)
4. RS422A
5. RS422B
6. Terminate preamplifier

Communication protocol

The amplifier communicates with the display unit in the shack via serial data at 38400 baud. The next issue was how to send the information to the remote display. Inspired by the NMEA protocol used for communication of output data from GPS modules, I decided to use a fixed format, comma delimited 'sentence' structure. A typical sentence might be:

@@27.8,17.0,200,27.8,17.0,200,400,015,096,TAFP0 ;

All sentences begin with the identifier @@. The above example translates to V_left = 27.8 V, I_left = 18 A, Power_left = 200 W, V_right = 27.8 V, I_right = 17 A, Power_right = 200 W, Power_fwd = 400 W, Power_reverse = 15 W, Temperature = 96°F, followed by four status flags and an error digit.

The status flags are T, F, A, and P. These stand for T = Transmit, A = Antenna connected to preamp, F = fan running and P = Preamp unterminated (i.e. connected to antenna). If a flag is active, the respective letter is sent; if not, a space is sent. Normal status examples are "TF 0" on transmit and " AP0" on receive (note the spaces).

The last digit is 0 if there are no errors, 1 = "over voltage error", 2 = "over current error left", 3 = "over current error left", 4 = "over temperature error" and 5 = "reverse power error".

Circuit

When the remote monitor is in use, the local LCD display mounted on the front panel of the amplifier is disabled to save processing time and speed up the rate at which the data can be sent to the remote unit. The Transmit LED and Preamp Terminated LED on the amplifier continue to function as before, but the third LED is used to show that serial data is being sent to the remote unit.

The remote monitor also has three LEDs which indicate Transmit, 'Data Activity' (showing that a correctly formatted data sentences are being received from the amplifier) and Alarm; once again the Alarm LED is supplemented by more detail on the LCD display. There are also two switches. One momentary-make switch resets the alarm, and should only be used after corrective action has been taken. The other switch is a SPST for remote control of the preamplifier termination.

The circuit diagram of the version for remote controller is very similar to the local version (Figure 2). The main differences are that it has no LCD display but includes the MAX481 RS422 interface chip.

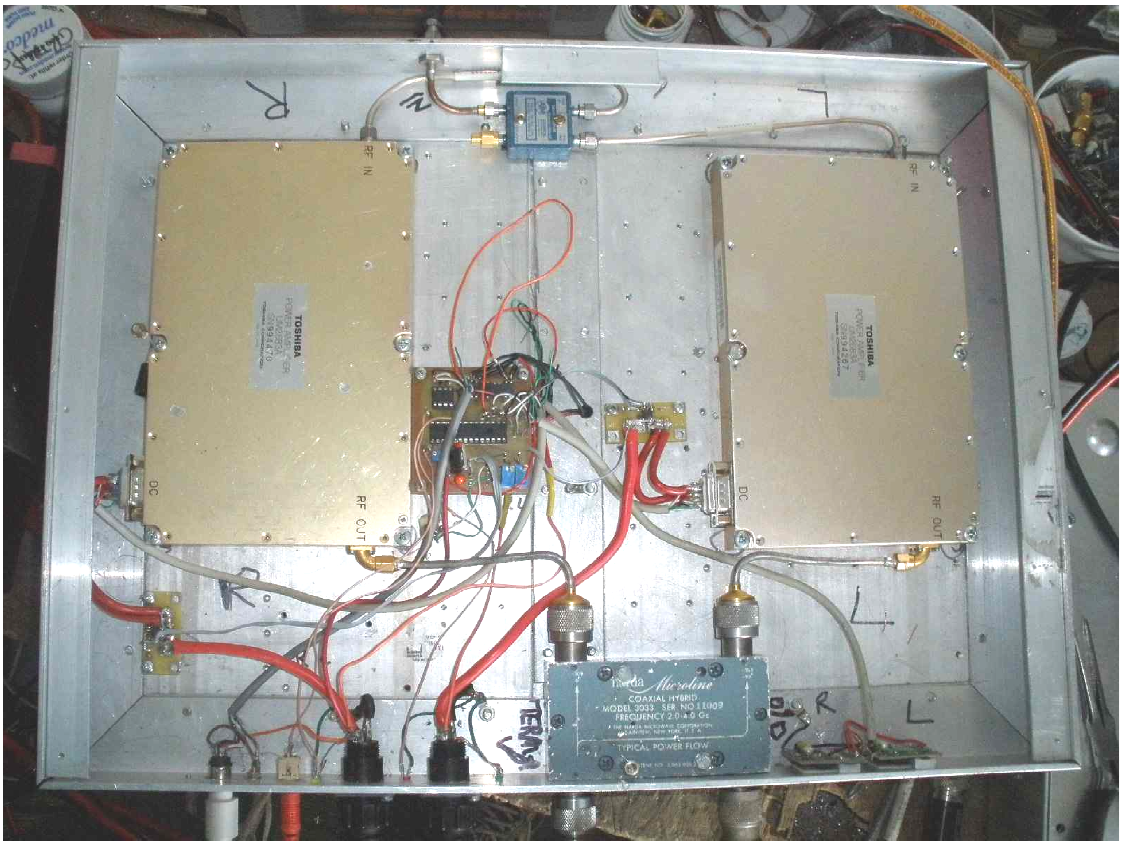
The remote display is yet another PIC 16F887, with both the LCD display and a MAX481 and running similar software.

Other Amplifiers

In the rest of this paper I will briefly describe the other two amplifiers that are being controlled in a similar way. I will mostly highlight the differences from the amplifier just described, and once again, all the image and .sch files are in my folder on the Conference DVD.

Dual Toshiba amplifier, 100 W at 3400 MHz

This amplifier consists of a pair of Toshiba UM2683A 50W modules with a pair of combiners [2]. The monitoring requirements are similar to the W6PQL amplifier, but this unit is designed only for a remote LCD display because there was insufficient room for a local display on the amplifier chassis.



As each amplifier takes 17 A at 12.0 V, this originally necessitated two separate 12 V power supplies so this controller has two voltage monitors. The current trip is set at 18 A per amplifier and the voltage trip is set at 14.0 V. The temperature that trips the amplifier into permanent bypass mode is 110°F. The fan runs continually when the amplifier is transmitting. On receive the fan runs if the chassis temperature exceeds 92°F and stops when the amplifier chassis cools to 90°F.

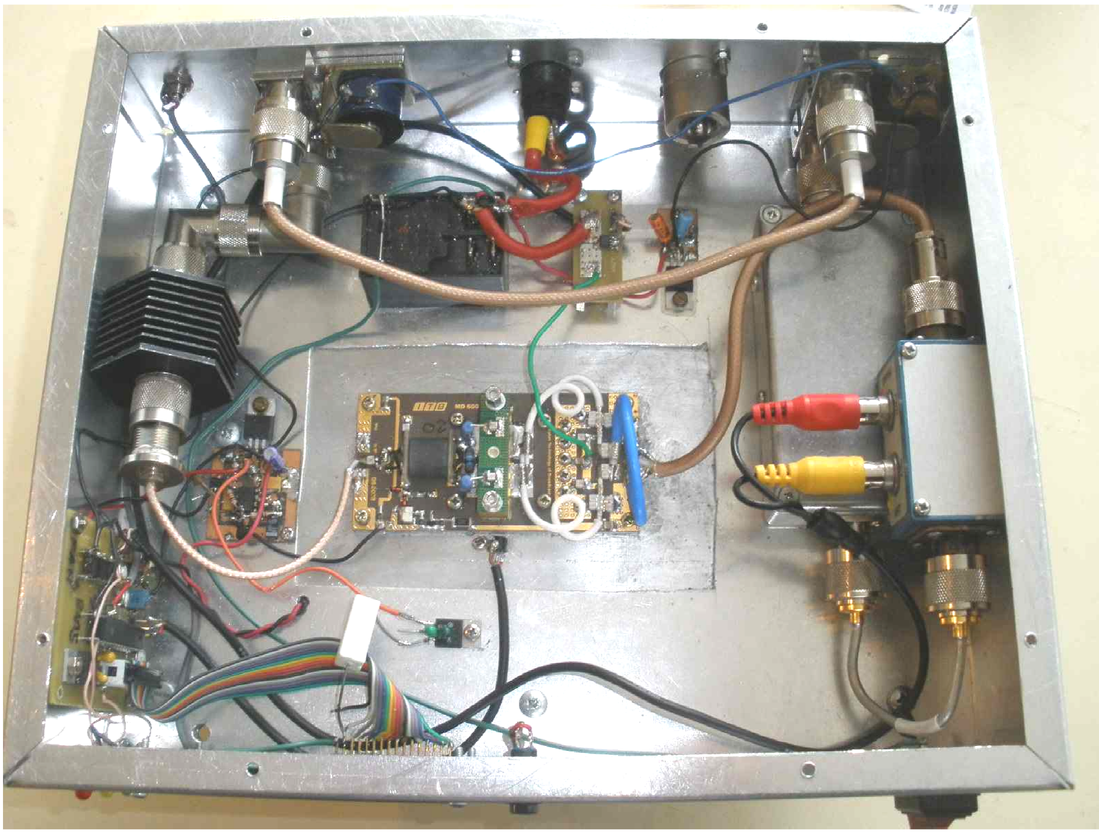
Each of the Toshiba amplifiers provides a voltage that indicates relative output. As well as being applied to the PIC (through a potential divider to protect the inputs) these two signals drive a pair of LM3914 LED bargraph displays. Along with the three status LEDs, this gives sufficient local monitoring of the amplifier status. A dual directional detector is attached to the amplifier output and the forward and reverse voltages are applied to the PIC. These inputs are calibrated, and at the remote monitor the PIC

displays them as total power. The RF outputs from the individual units are displayed only in relative terms, which is sufficient to see that the power outputs are balanced.

Full circuit details and program listings for the local controller and remote display units are given on the Conference DVD.

I0JXX amplifier, 500 W at 144 MHz

The I0JXX 500MOD144 144 MHz 500 W amplifier module uses a single MRF6V2600H device operating from 48 V. It requires around 3 W of drive for full output and takes a maximum of 15 A. The monitoring and control circuitry is similar to previous designs, with a few differences outlined below.



As cable losses are smaller at 144 MHz, this amplifier is operated in the shack and has no facility for a remote display. The amplifier has an internal pair of RF relays to bypass the amplifier allowing it to be placed inline with the 144 MHz transceiver. The RF relays require a 12 V supply which is derived from the 48 V rail using a TL783 high-voltage adjustable regulator (48V exceeds the input voltage limit of the more common LM317, but otherwise the circuit is very similar). On receive, a gate bias of –5 V is needed to prevent the PA device from drawing current and generating noise. To achieve this, the +48 V supply is regulated down to 12 V by another TL783, followed by a LT1054 negative supply generator and a FET Tx/Rx switch.

The current trip is set at 16 A and the voltage trip at 48.6 V. The temperature thresholds are the same as for the Toshiba 3.4 GHz amplifier.

Future Improvements

While developing the units described above, some ideas for possible improvements came to mind:

1. Excessive reverse power seems to be one of the commonest causes of amplifier failure. Currently the controller looks at the inputs sequentially and if there is an issue with a parameter when it gets to read it, it takes action. To get the controller's attention faster in case of a mishap, the reverse power voltage could be fed to a comparator which senses if the voltage is excessive and provides an interrupt to the microprocessor. This interrupt gets the immediate attention of the controller, which can then take corrective actions more quickly.
2. Use Ethernet for communications. Many commercial cellular amplifiers have a nice web-based GUI that allows monitoring and adjustment of selected operational parameters. This is the technique I use to control my station in Texas from England, so it should certainly be possible to control an amplifier over a few tens of feet.
3. Instead of using the diode detectors to measure forward and reverse powers, use a pair of Logarithmic RF Amplifiers such as the AD8307. These have a linear output over a wider dynamic range, allowing finer power resolution. The difference between the two output signals at any instant would also give a measure of return loss which is independent of the RF power level.

Conclusion

Hopefully this presentation will help those owning high power solid state amplifiers to keep them in a working state by giving them better protection and status monitoring.

References

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